At the time of issue this report has not been published. Any author desiring to quote this paper should refer to it as "A paper of the Meteorological Research Committee (London), M.R.P. No. 874 by Mr. J.G. MOORE
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M.R.P.874
S.C.II/176
27th August, 1954.

AIR MINISTRY

METEOROLOGICAL RESEARCH COMMITTEE

Average Pressure and Temperature of the Tropopause

by
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1. Summary

Charts of the world (Figs.1-8) are reproduced showing the average pressure and temperature of the tropopause in the mid-season months, a distinction being made between "polar" and "tropical" tropopauses.

An attempt is made to delineate the region in which both polar and tropical tropopauses are found and to estimate their respective frequencies of occurrence.

The variation through the year of the monthly averages of the pressure and temperature at the tropopause is investigated.

2. Definitions

In general it was not found possible to apply a rigid definition of the tropopause to the available data. Many of the data were taken from publications of other meteorological services or received in manuscript form with the mean values already evaluated. In these doubt often existed as to the methods used in assessing the tropopause pressures and temperatures and the definitions, if any, that had been employed.

When the tropopause pressures and temperatures were extracted from individual ascents, the following tentative definitions were applied. They are those provisionally adopted for M.O.555 (Upper Air Data).

Troposphere

The troposphere is the layer of the atmosphere immediately around the earth's surface in which temperature normally falls with height. The fall must, in general, exceed 2°C. in any Km. of height, but layers of lower lapse rate may occur:

(a) in the lowest 2 Km.

(b) at higher levels in the troposphere provided that the thickness of such a layer is less than 1 Km. and that the fall in the subsequent half Km. is greater than 1°C.

Stratosphere

The stratosphere is the layer of the atmosphere above the troposphere in which temperature either increases or changes little with height. Any fall in temperature must not exceed 2°C. in any Km. of height. There may be shallow layers of lapse rate greater than 2°C. in a Km. of height within the stratosphere provided that the general criterion holds. Such a layer cannot occur at the boundary.

/Tropopause

Tropopause

The tropopause is the boundary between stratosphere and troposphere and may be defined either as the top of the troposphere or as the base of the stratosphere. If the two coincide there is a single tropopause. If the top of the troposphere and base of the stratosphere determined from the above definitions do not coincide two tropopauses are reported.

In the middle and high latitudes the base of the stratosphere and the top of the troposphere normally coincide in a single surface. In the tropics, also, stratosphere and troposphere are normally coterminous. In the sub-tropics, however, two tropopauses are frequently found, an upper, which appears to be a poleward extension of that over the tropics, and a lower which appears as an equatorward extension of the tropopause of middle latitudes. These are referred to as the tropical and polar tropopauses respectively.

3. Data available and methods of computing

The data used were mainly radio-sonde observations made between the years 1940 and 1952 with observations for earlier years at a few stations. The number of years available at the different stations varied considerably and no attempt has been made to adopt a uniform period.

Three classes of data may be distinguished:-

A. Average values taken directly from publications and MS. data of other meteorological services. For these the definitions are for the most part unknown, and for some regions no rigid definition appears to have been used.

B. Average values computed from individual ascents using the definitions set out above.

C. Values obtained by estimation from average temperatures at standard pressure levels.

The regions with data in these different classes and the periods covered are shown below:-

A		B		C	
Africa	1948-53	Alaska	1949-51	Caribbean	1940-43
Australia	1949-52	British Isles	1946-53	Pacific Is.	1950-51
Canada	1942-50	China	1942-44	U.S.S.R.	1949-51
Germany	1948-52	Falklands	1948-53		
Hong Kong	1950-53	Greenland	1949-51		
Hungary	(1913-14 (1927-40	Iceland	1949-51		
India	1926-40	Japan	1949-52		
New Zealand	3-9 years	Mediterranean and Middle East (M.O. stations)	1950-51		
Norway	1949-51	Ocean stations	1949-52		
		Switzerland	1948-51		
		U.S.A.	1949-51		
		U.S.S.R.	1949-51		

In computing the averages for class B, mean monthly values of pressure and temperature were evaluated for the individual years and the long period averages were obtained by giving equal weight to each year. When the number of observations in any month was less than ten the monthly mean for that month was weighted: months with 10 or more observations were given unit weight, months with 9 observations .9 and so on.

Data in class C were used only when no data were available in classes A or B. For these the pressure and temperature at the tropopause were assessed by a method due to Flohn(1). In this method the average monthly temperature at the

station was plotted against the logarithm of the pressure. Two straight lines, drawn to fit the curve, one in the upper troposphere and the other in the lower stratosphere, were extended to intersect. Their intersection was taken as giving the average pressure and temperature at the tropopause. This method can of course only be used in regions where a single tropopause is normally reported and even there it is to some extent subjective. The values thus found will normally differ from those obtained by averaging the values for individual ascents (class B) which may be regarded as the true values. In order to test the extent to which the two differ a comparison was made of data obtained by the two methods, with the following result:

In regions of polar tropopause it was found that in January and April the difference of pressure was not systematic. The values in general agreed to within about 15 mb. though occasionally the difference was 20 mb. In July and October, on the other hand, the tropopause pressure obtained from the mean curve was always larger than the true mean, the difference being of the order of 15-20 mb. except in the Arctic where it reached 50 mb. in July and 70 mb. in October. Temperature differences showed greater regularity and throughout the year the temperatures assessed from the mean curves (class C) were some 2 or 3°C. higher than the true values.

In regions of tropical tropopause it was found that assessments of tropopause pressure from the mean curves gave a reasonable approximation to the true values though at some places they appeared to be too high. Values of tropopause temperature obtained from the mean curves were about 3°C. higher than the true values.

In spite of these differences, isopleths of pressure and temperature drawn from values obtained from mean curves showed for the most part the same general pattern as the true isopleths even though the actual values of the isopleths differed. This similarity proved of no small assistance in drawing isopleths over regions such as Russia where data were very sparse.

4. The charts (Figs.1-8)

The average values of pressure and temperature at the tropopause in the mid-season months are set out on eight Mercator charts of the World extending from 75°N. to 60°S. (Figs.1a to 8a) with supplementary charts, on circumpolar projection, for the North Polar region (Figs.1b to 8b). Isopleths are drawn for intervals of 20 mb. of pressure for the polar tropopause, and 10 mb. for the tropical tropopause. Isopleths of temperature are drawn at intervals of 4°C. for both types of tropopause. Temperatures are given in degrees absolute (273° + C). Isopleths for the polar tropopause are shown by full lines, broken lines being used where isopleths for intermediate values of pressure and temperature are drawn, those for the tropical tropopause by lines consisting of alternate dashes and dots.

Method of plotting and of drawing the isopleths

Values of pressure and temperature are plotted for all stations for which they are available. Where there are two tropopauses, the values are plotted one above the other, the figures for the polar tropopause being on the poleward side; the figures for the tropical tropopause are plotted in italics. The reliability of the values is indicated by underlining the figure if it is based on a period of four years or more, and by enclosing it in brackets if it is based on only one year or on less than 20 observations. On the working charts the period of years on which each value was based was also plotted but these figures have not been reproduced in the final charts.

In drawing the isopleths more weight was given to values in classes A and B than to those in class C, and the longer the period of the record the greater was considered the reliability.

As far as possible the isopleths were drawn to fit the plotted values, smoothing where the lines appeared unduly tortuous.

/In

In regions where few data for the polar tropopause were available certain general principles were borne in mind: first, that unless there was strong evidence to the contrary the isopleths should not diverge much from the mean wind flow of the middle troposphere i.e. from the pressure contour lines and secondly, that in temperate latitudes there is a high positive correlation between the height of the tropopause and the temperature of the troposphere(2) and that pressure at the tropopause is therefore likely to be low over regions where the troposphere is relatively warm.

In equatorial regions, if data were insufficient, the isopleths were drawn largely by analogy with the temperature at 100 mb.

Over the greater part of the northern hemisphere the isopleths have been drawn with reasonable confidence in so far as their main features are concerned, except perhaps over Russia where data were very scanty. In the tropics although data were not numerous the values at different stations showed good agreement and errors are not therefore likely to be large. It must be borne in mind, however, that earlier investigations (3,4) indicate that the structure of the tropopause in equatorial regions is more complex than has been envisaged in this work. Over the southern hemisphere except in the region of Australasia, information was available for very few stations and little reliance can be placed on the lines.

5. The region with two tropopauses

In the sub-tropical regions of both hemispheres, roughly between latitudes 35° and 45°, two tropopauses are frequently indicated on the curves of ascent, but on some occasions there may be a polar tropopause only and on others a tropical only. An attempt was therefore made to determine the frequency with which the different types occurred.

In order that the results should not be biased by the loss of records at great heights the data used were as far as possible restricted to those which reached 80 mb., unless below that level an upper tropopause had already been reached or its probable existence had been indicated by the presence of a tropospheric lapse rate above the lower tropopause.

The percentage frequencies of the different types of tropopause are shown in the following table:

/Percentage frequency

Percentage frequency of occurrence of polar and tropical tropopauses and of two tropopauses in the sub-tropics

Station and Period	Position	JANUARY				APRIL				JULY				OCTOBER			
		Polar Trops.	Tropical Trops.	Two Trops.	No. of Ascents	Polar Trops.	Tropical Trops.	Two Trops.	No. of Ascents	Polar Trops.	Tropical Trops.	Two Trops.	No. of Ascents	Polar Trops.	Tropical Trops.	Two Trops.	No. of Ascents
		per cent.				per cent.				per cent.				per cent.			
Wakkanai 1950-52	45°25'N. 141°41'E.	100	11	11	119	99	22	21	136	73	81	54	151	91	56	47	158
Ship X Ray 1950-52	39°N. 153°E.	97	74	72	78	88	64	52	97	18	95	12	145	19	98	17	129
Shionomisaki 1950-52	33°27'N. 135°46'E.	43	96	38	136	83	89	72	119	4	100	4	144	2	100	2	161
Ship T July 1950 -Oct. 1952	29°N. 135°E.	11	100	11	72	37	100	37	101	0	100	0	146	0	100	0	159
Gibraltar 1950-51	36°09'N. 05°21'W.	97	51	48	69	98	45	43	58	35	80	15	72	63	62	25	79
Malta 1950-51	35°50'N. 140°27'E.	96	93	89	99	98	92	89	83	10	100	10	113	82	88	70	73
Nicosia 1950-51	35°09'N. 33°17'E.	95	96	91	105	100	95	95	103	2	100	2	111	67	75	42	109
Habbaniya 1950-51	33°22'N. 43°34'E.	72	100	72	110	97	97	94	108	0	100	0	123	48	98	46	112
Benina 1950-51	32°05'N. 20°16'E.	57	98	54	123	78	75	54	106	0	100	0	96	19	93	12	115
Bahrein 1950-51	26°16'N. 50°37'E.	21	100	21	97	41	100	41	102	0	100	0	119	0	100	0	116

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The table shows that, in any month, as the latitude increases, the polar tropopause occurs more and more frequently until at a certain latitude it is always present, whereas the tropical tropopause occurs less and less frequently until finally it does not occur at all; similarly as the latitude decreases the tropical tropopause becomes more and more frequent until equatorward of a certain latitude it is always present whereas the polar tropopause becomes less and less frequent and finally ceases to appear at all.

In order to give an indication of the poleward limit of the tropical tropopause and equatorward limit of the polar tropopause, areas on the charts are "hatched" where the frequency of both types is greater than 10 per cent. These limits are largely conjectural especially in the southern hemisphere.

The charts show that the tropical tropopause extends further poleward in summer than in winter, reaching furthest north in July in the northern hemisphere and furthest south in January in the southern. The polar tropopause extends further towards the equator in winter than in summer but it reaches its lowest latitude in April in the northern hemisphere and in October in the southern.

At most stations in the zone of two tropopauses the polar tropopause is most frequent in spring and least frequent in summer, e.g. at Benina where it occurs on 78% of occasions in April but vanishes entirely in July. The tropical tropopause is most frequent in summer and generally least frequent in spring, e.g. at Gibraltar where it occurs on 80% of occasions in July compared with 45% in April.

In the transition regions from two tropopauses to a single tropopause the isopleths of temperature and pressure of the less frequent tropopause should be treated with reserve as the values are valid only for the relatively few occasions on which the tropopause exists.

6. Variation through the year

Averages for all twelve months of the year have been computed for a few stations where the necessary data were available, but for the most part the variation through the year has to be judged from data for the mid-season months only. Diagrams for selected stations are shown in Figs.9 and 10.

Polar tropopause

In the northern hemisphere the charts for the mid-season months show that, in general, the pressure at the tropopause is highest in April and lowest in July. In most parts the difference is of the order of 40-60 mb. but it is greater over the large land masses and probably reaches 80-100 mb. over Russia. Temperature is highest in July when pressure is lowest, and lowest in January. The range of the monthly averages is about 4-6°C. except over the large land masses where it is about 9°C.

In the southern hemisphere in the regions where there is a single polar tropopause its pressure shows little variation through the year. The temperature is lowest in winter (July) and highest in summer (January) but the range of variation is difficult to assess owing to lack of data. In Australasia, in the region of two tropopauses, the variation of pressure at the polar tropopause is similar to that in the northern hemisphere with the appropriate reversal of season i.e. highest pressure in winter or spring and lowest in summer (frequently in January or February) with a range of 40-60 mb. Temperature on the other hand seems to reach its highest value in spring (around October) and its lowest in late summer or early autumn (February or March) i.e. several months earlier than would be expected on the analogy of the northern hemisphere. The range is of the same order of magnitude as that in the northern hemisphere. In the oceanic regions of the sub-tropics, away from land masses, the pressure at the tropopause probably varies little through the year.

/Tropical tropopause

Tropical tropopause

In the northern hemisphere the tropical tropopause generally shows higher mean values of both pressure and temperature in summer than in winter, the range being 15-20 mb. and 4-6°C. respectively.

In the sub-tropics of the northern hemisphere, however, at such stations as Malta and Habbaniya where two tropopauses occur frequently for a large part of the year, during the summer months when the polar tropopause ceases to exist or becomes infrequent the pressure and temperature of the tropical tropopause depart from this pattern and both fall instead of rising.

For those regions of the southern hemisphere where the tropical tropopause occurs frequently throughout the year, the few data available indicate that the annual variation of the pressure at the tropopause is less pronounced than that in the northern hemisphere. With a range of 10-15 mb. the monthly mean tropopause pressure reaches its highest value in winter or spring and lowest in summer or autumn. Temperature shows a range of 6-8°C. with highest values in spring and lowest in summer or autumn.

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Sources of Data

Class A

Africa

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Australia

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Hong Kong

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Norway

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Class B

Alaska

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British Isles

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China

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Falklands

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Greenland & Iceland

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Japan

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Mediterranean & Middle East (M.O. stations)

27. London, Met. Office. — MS. data.

Ocean Stations

28. U.S. Weather Bureau, Dept. of Commerce. — Data from microfilm.

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Switzerland

30.		Annalen der Schweizerischen Meteorologischen Zentralanstalt, Zurich, 1948-51.

U.S.A. & U.S.S.R.

31.	Washington, U.S. Weather Bureau.	Daily Series Synoptic Weather Maps, 1949-51.

Class C

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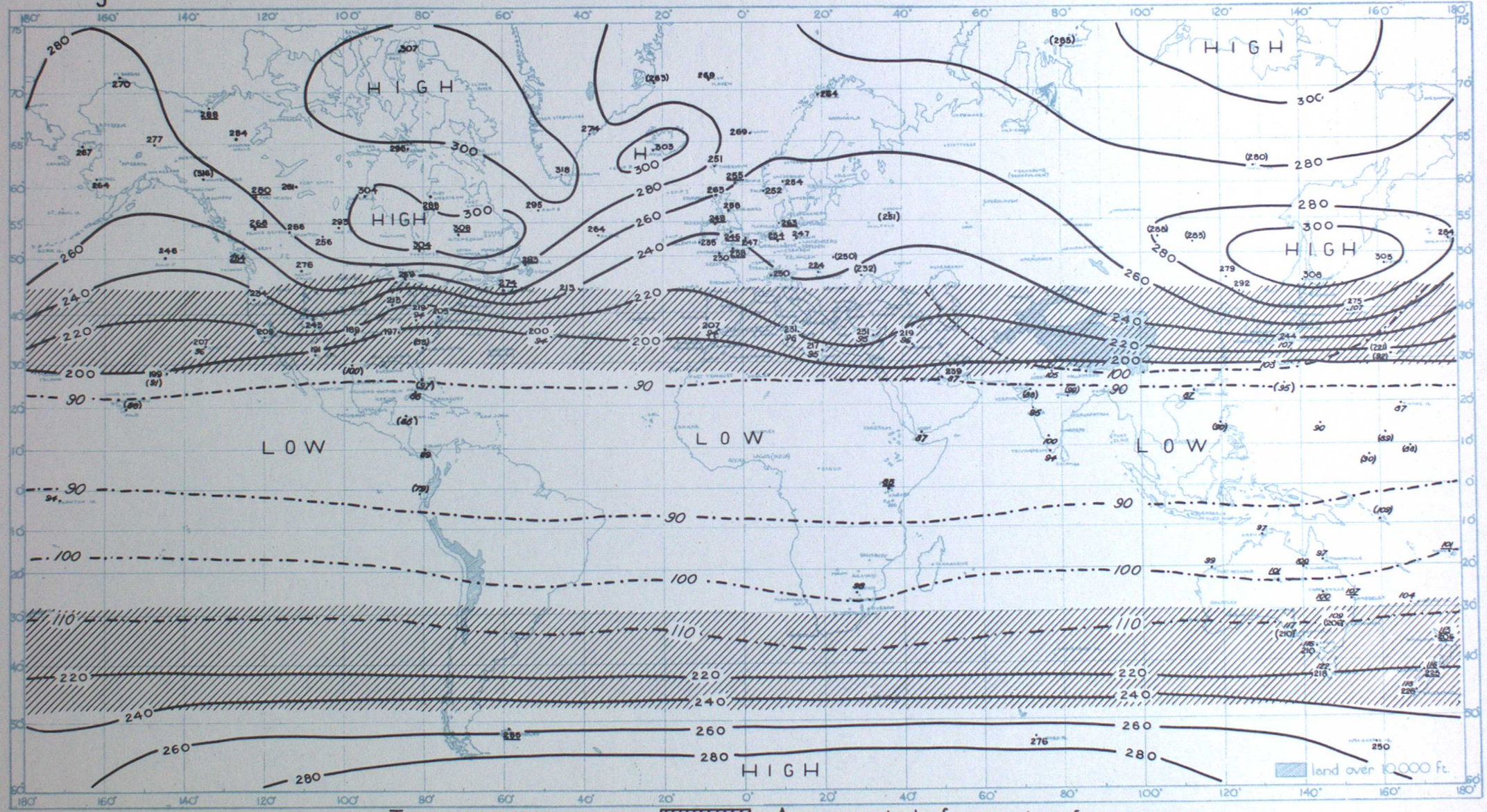
Fig. 1(a)

TROPOPAUSE PRESSURE (MB)

January M.R.P. 874



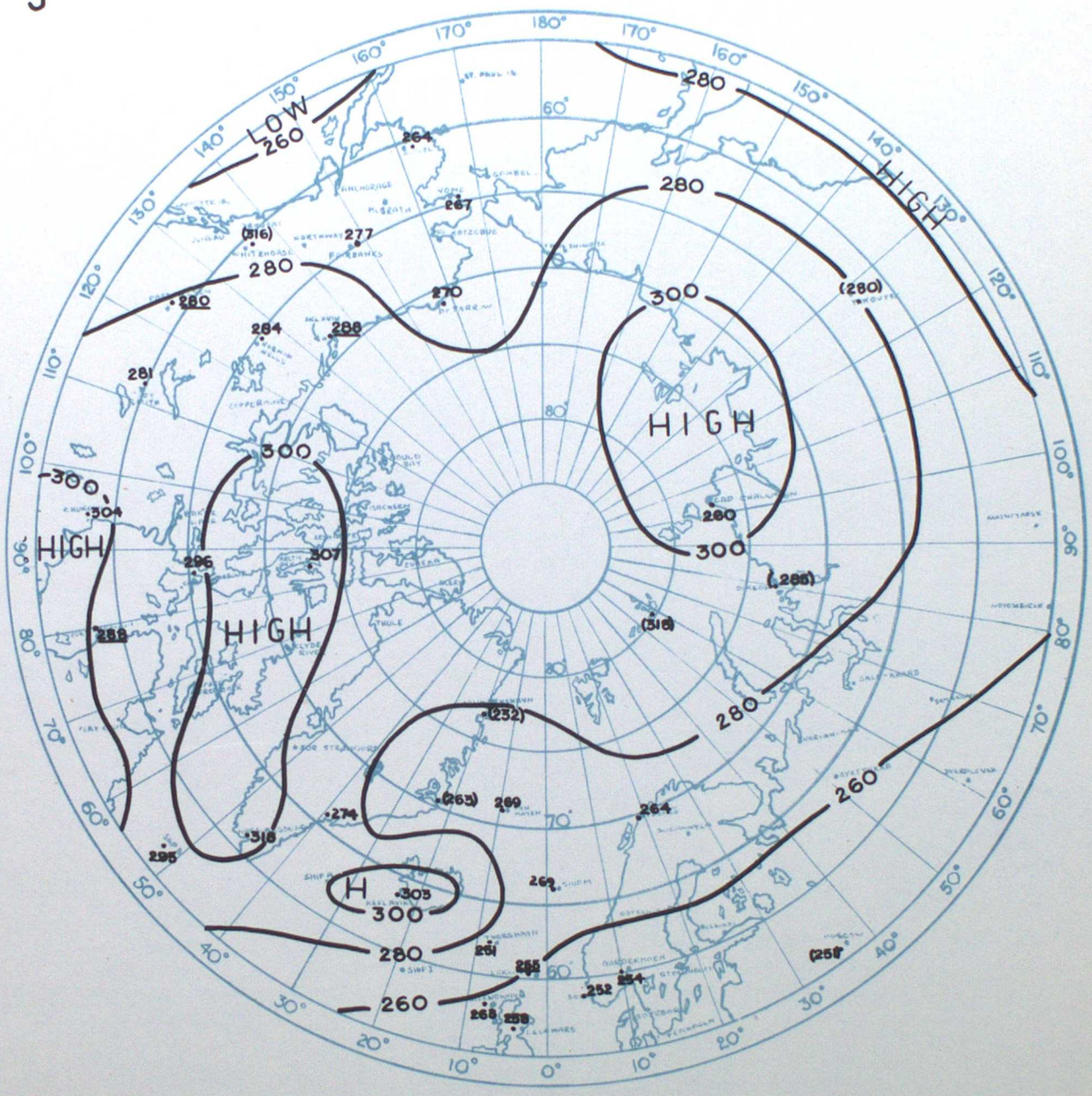
Tropical tropopause

Polar tropopause

Areas in which frequencies of occurrence of both tropopauses are greater than 10%

M.R.P. 874

Fig. 1(b) TROPOPAUSE PRESSURE (MB) January

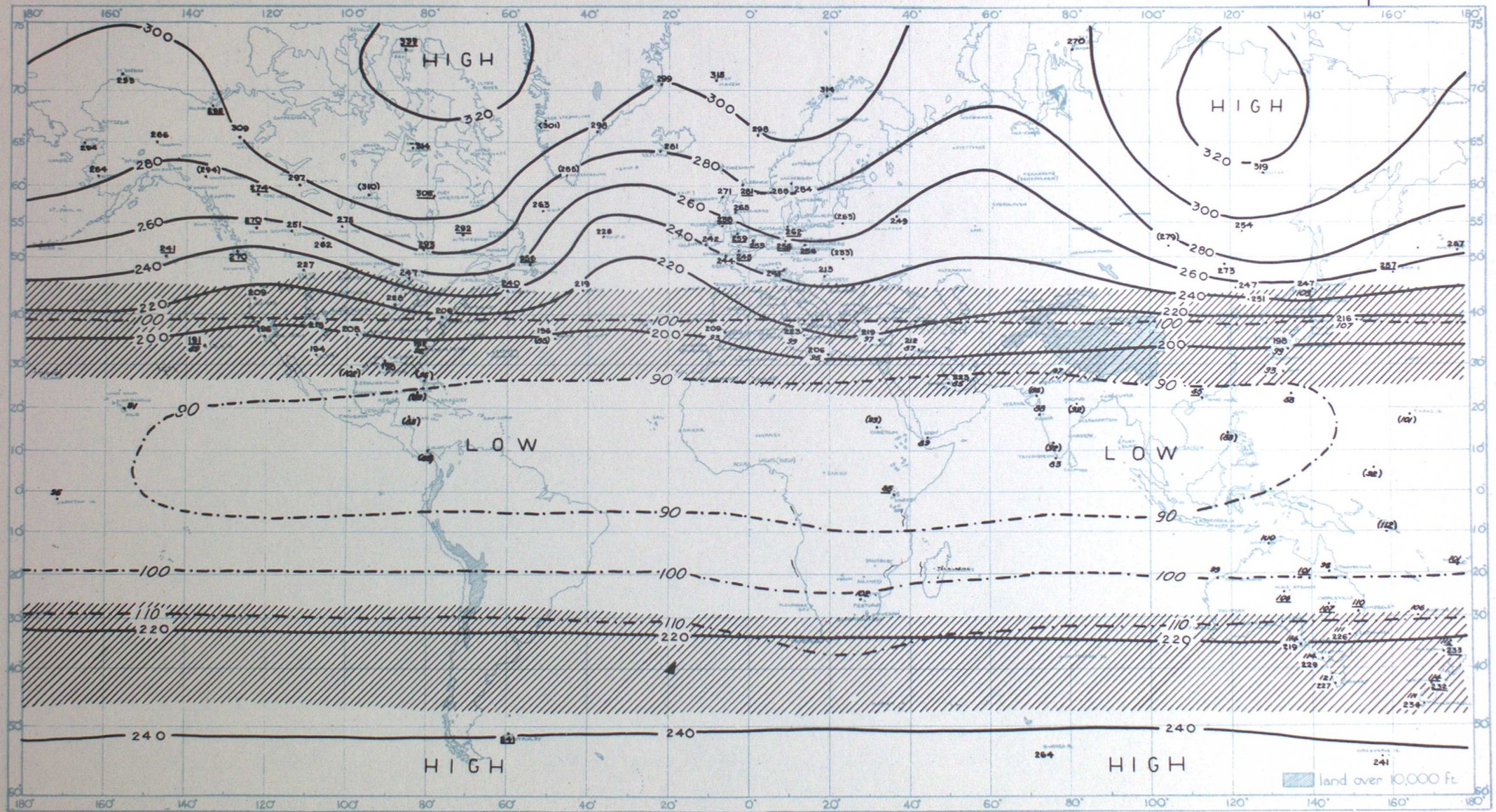


Polar tropopause

Fig. 2 (a)

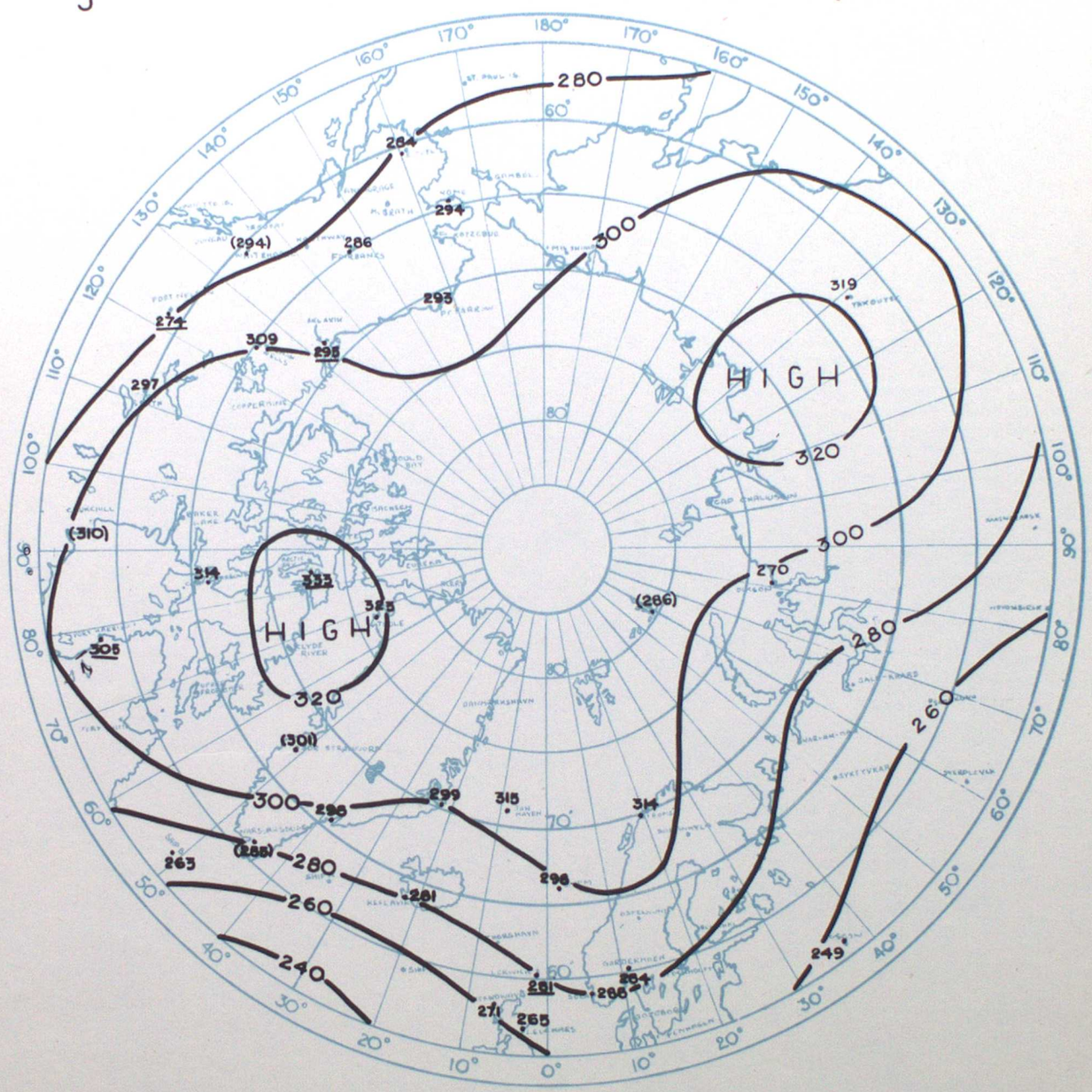
TROPOPAUSE PRESSURE (MB)

April MRP 874



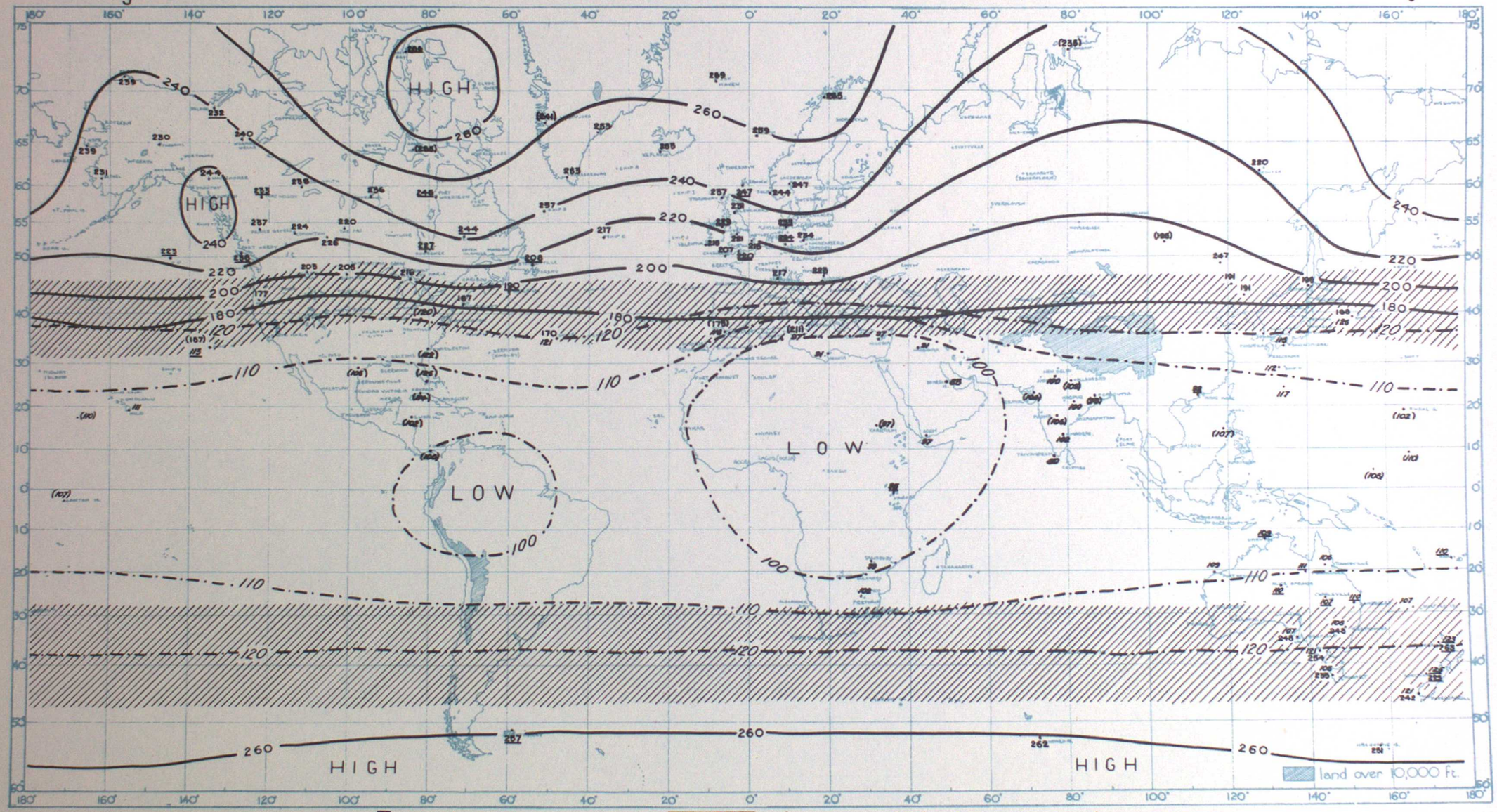
M.R.P. 874

Fig. 2(b) TROPOPAUSE PRESSURE (MB) April



Polar tropopause

Fig. 3(a) TROPOPAUSE PRESSURE (MB) July M.R.P. 874

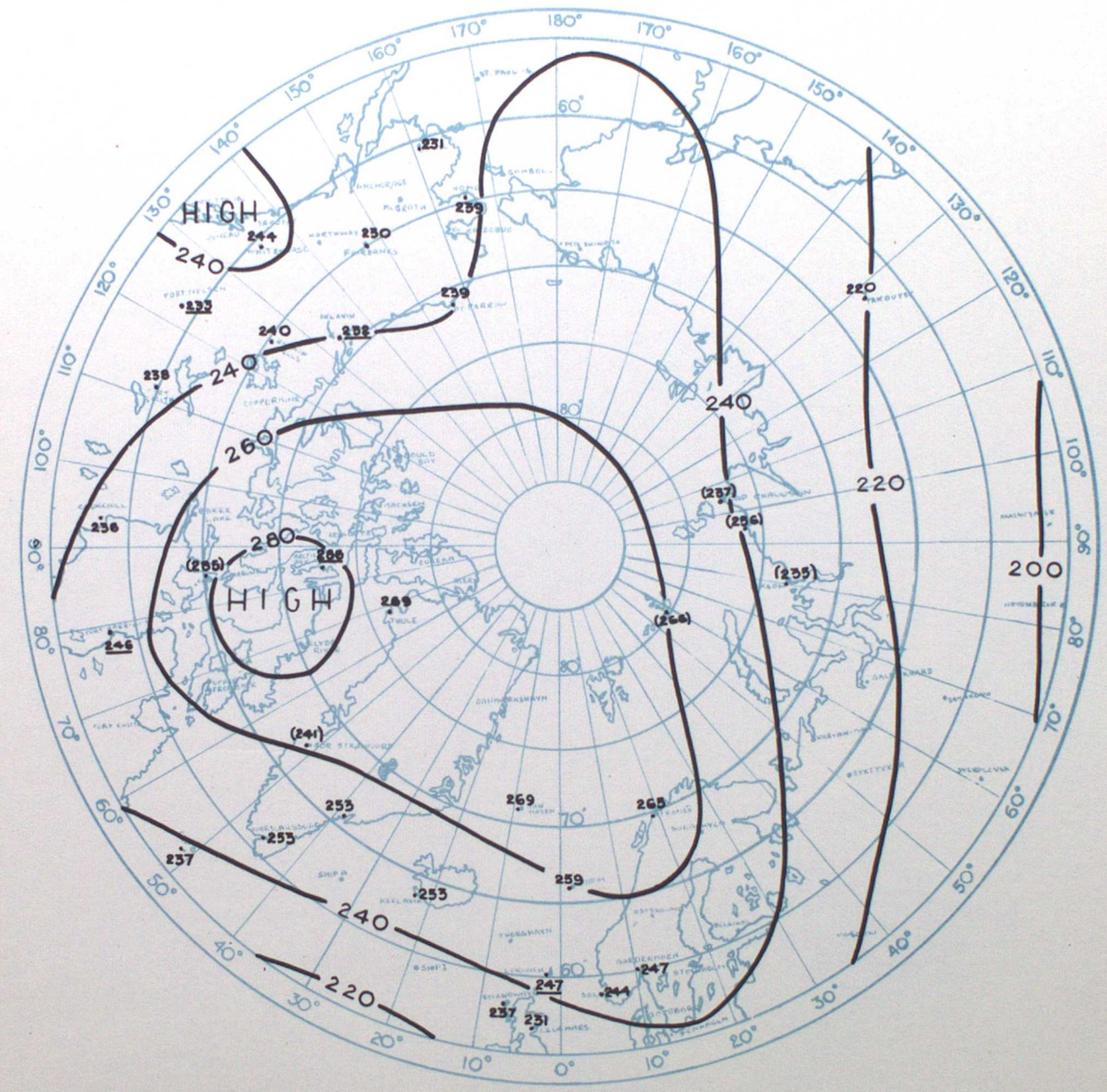


Tropical tropopause
Polar tropopause

Areas in which frequencies of occurrence of both tropopauses are greater than 10%

M.R.P. 874

Fig.3(b) TROPOPAUSE PRESSURE (MB) July



_____ Polar tropopause

Fig. 4(a)

TROPOPAUSE PRESSURE (MB)

October MRP 874

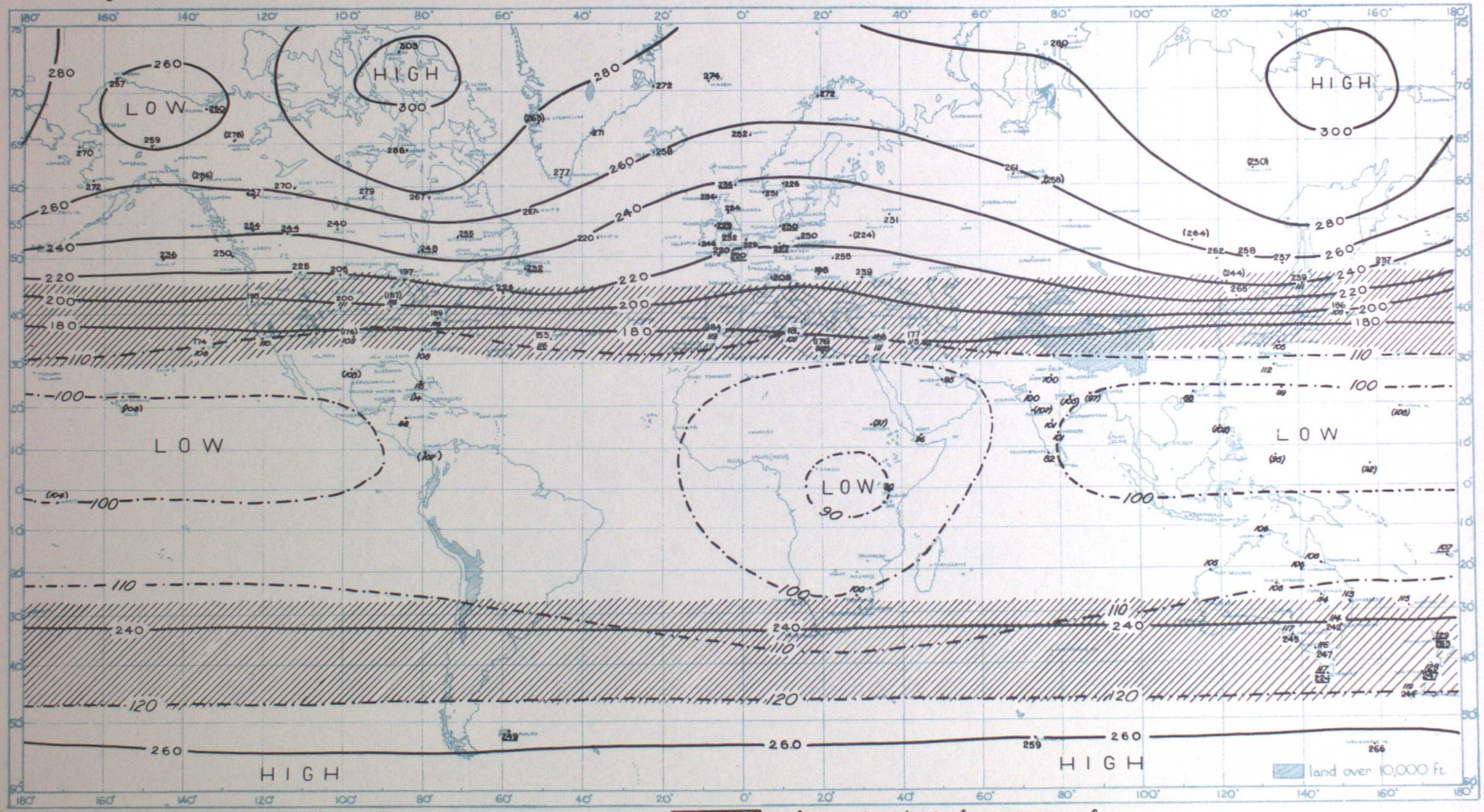
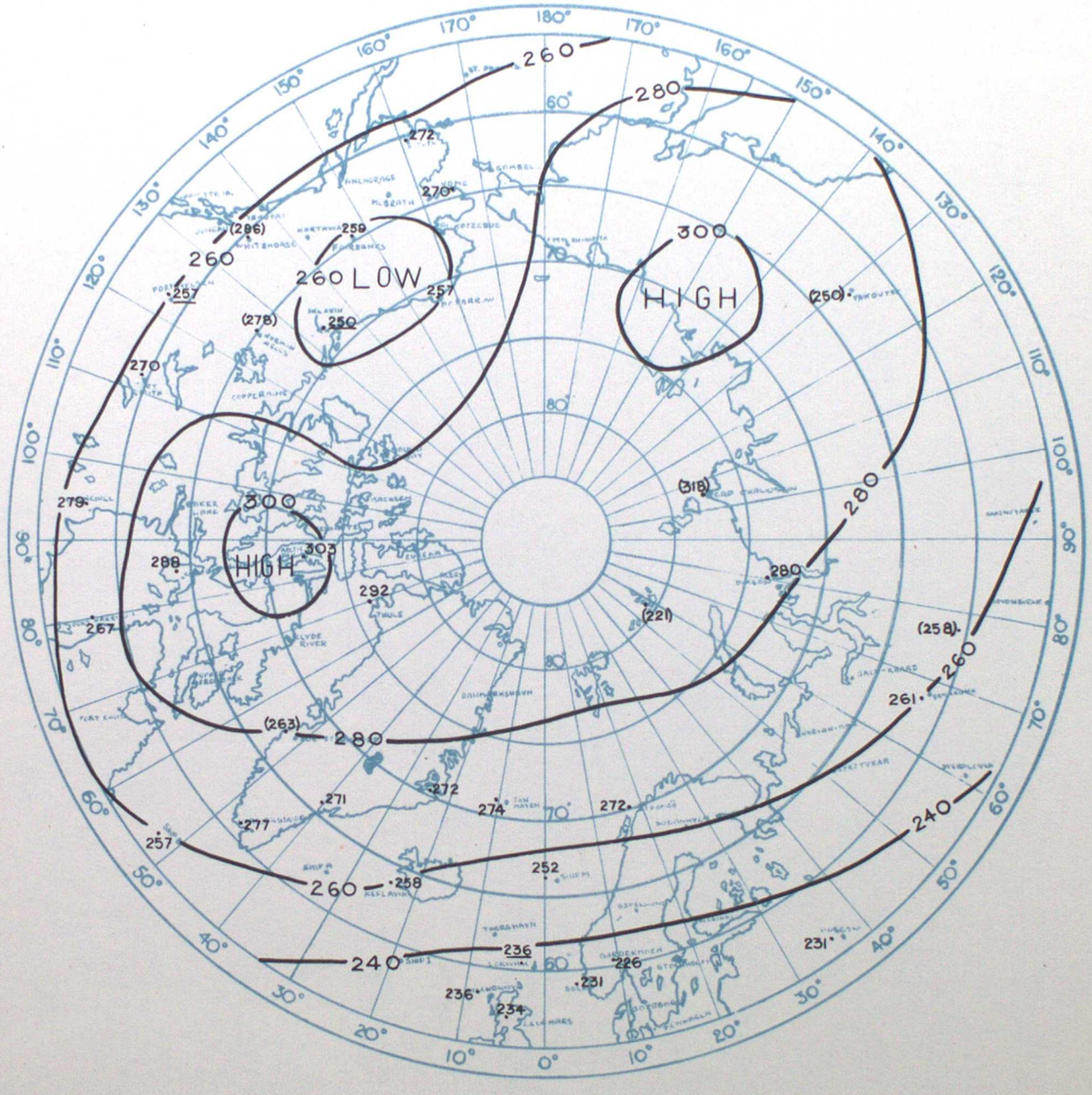


Fig. 4(b) TROPOPAUSE· PRESSURE (MB) October



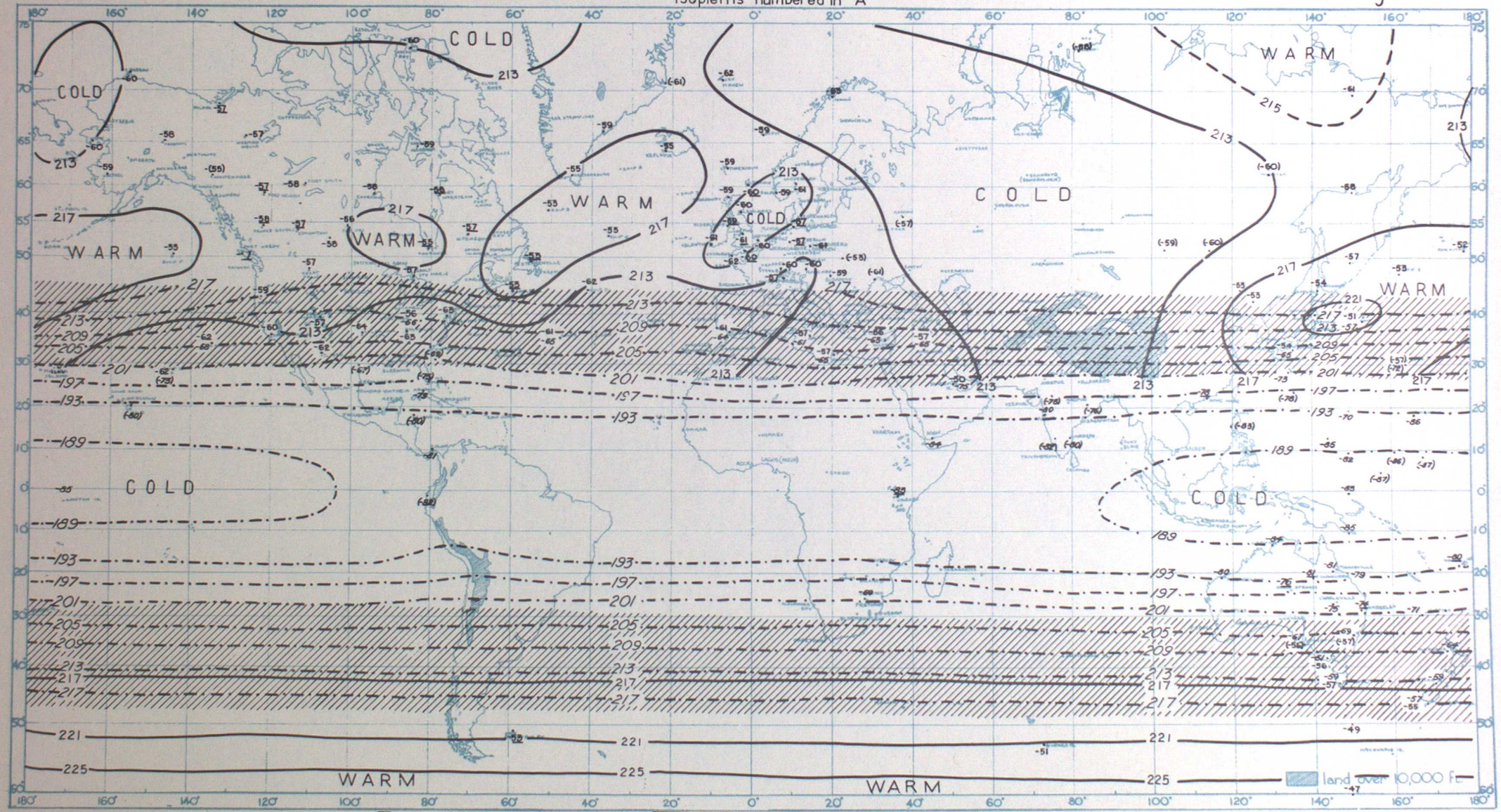
——— Polar tropopause

Fig. 5 (a)

TROPOPAUSE TEMPERATURE (°C)

Isopleths numbered in °A

January M.R.P. 874



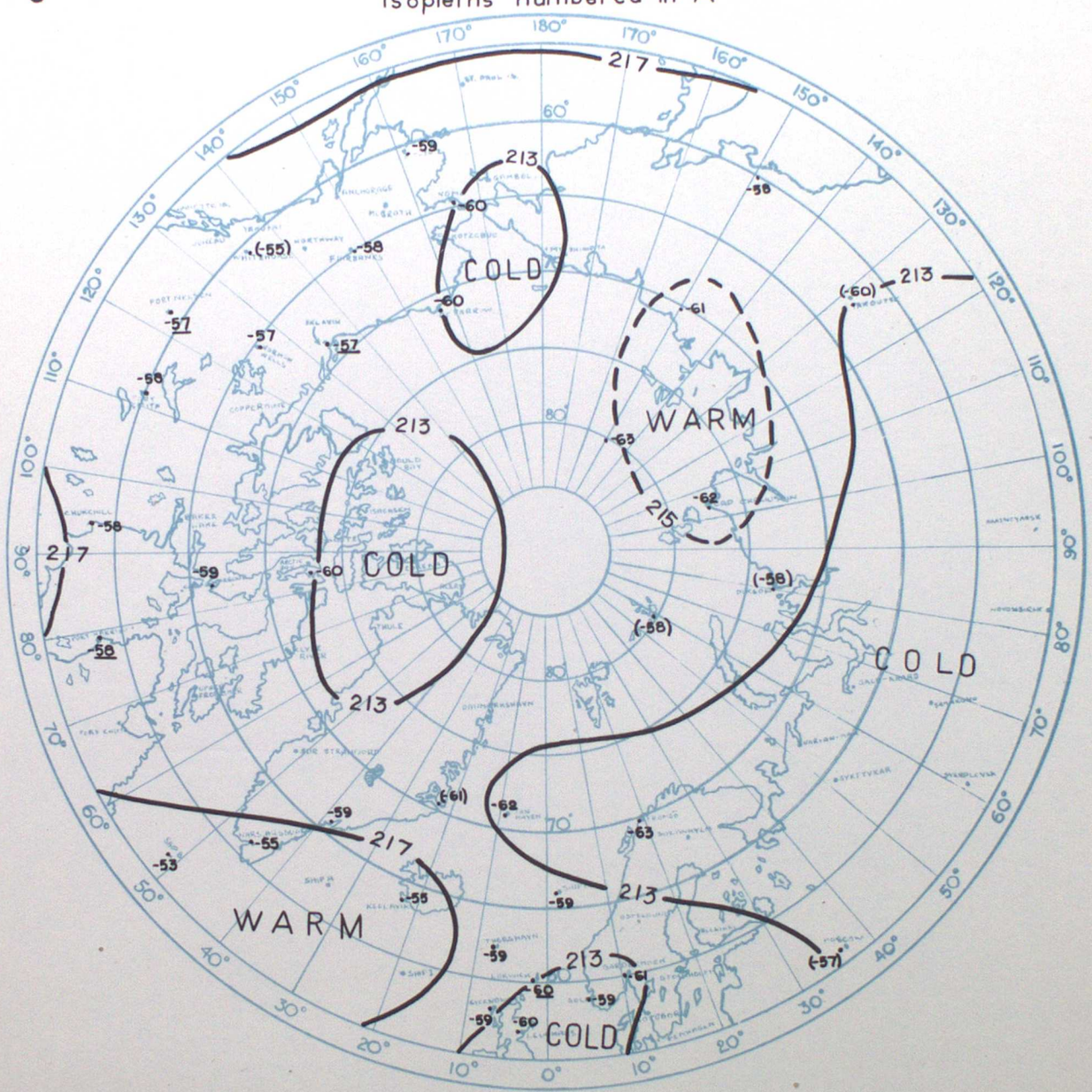
Tropical tropopause

Polar tropopause

Areas in which frequencies of occurrence of both tropopauses are greater than 10%

Fig. 5 (b) TROPOPAUSE TEMPERATURE (°C) January

Isopleths numbered in °A



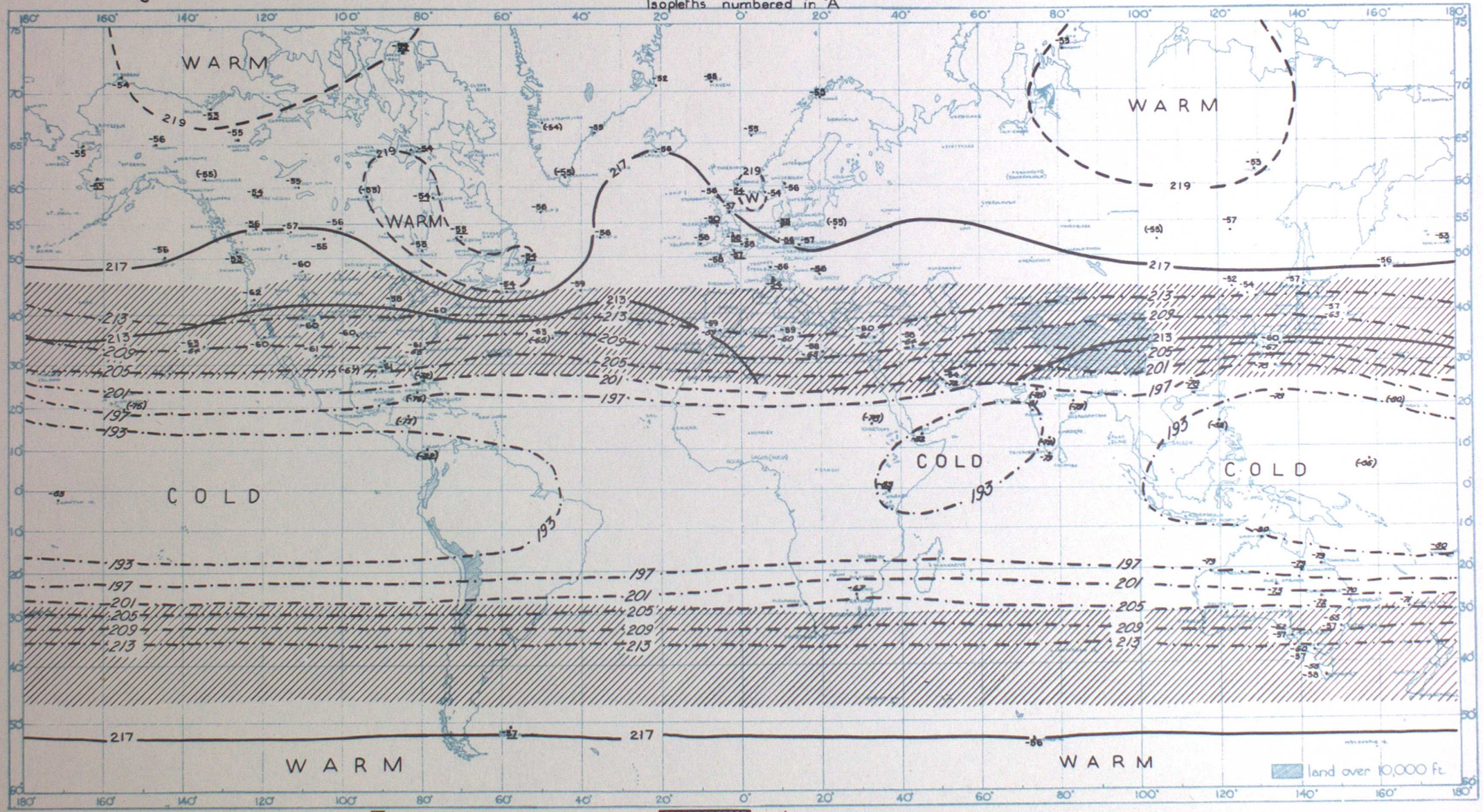
——— Polar tropopause

Fig. 6(a)

TROPOPAUSE TEMPERATURE (°C.)

Isopleths numbered in °A

April M.R.P. 874



Tropical tropopause

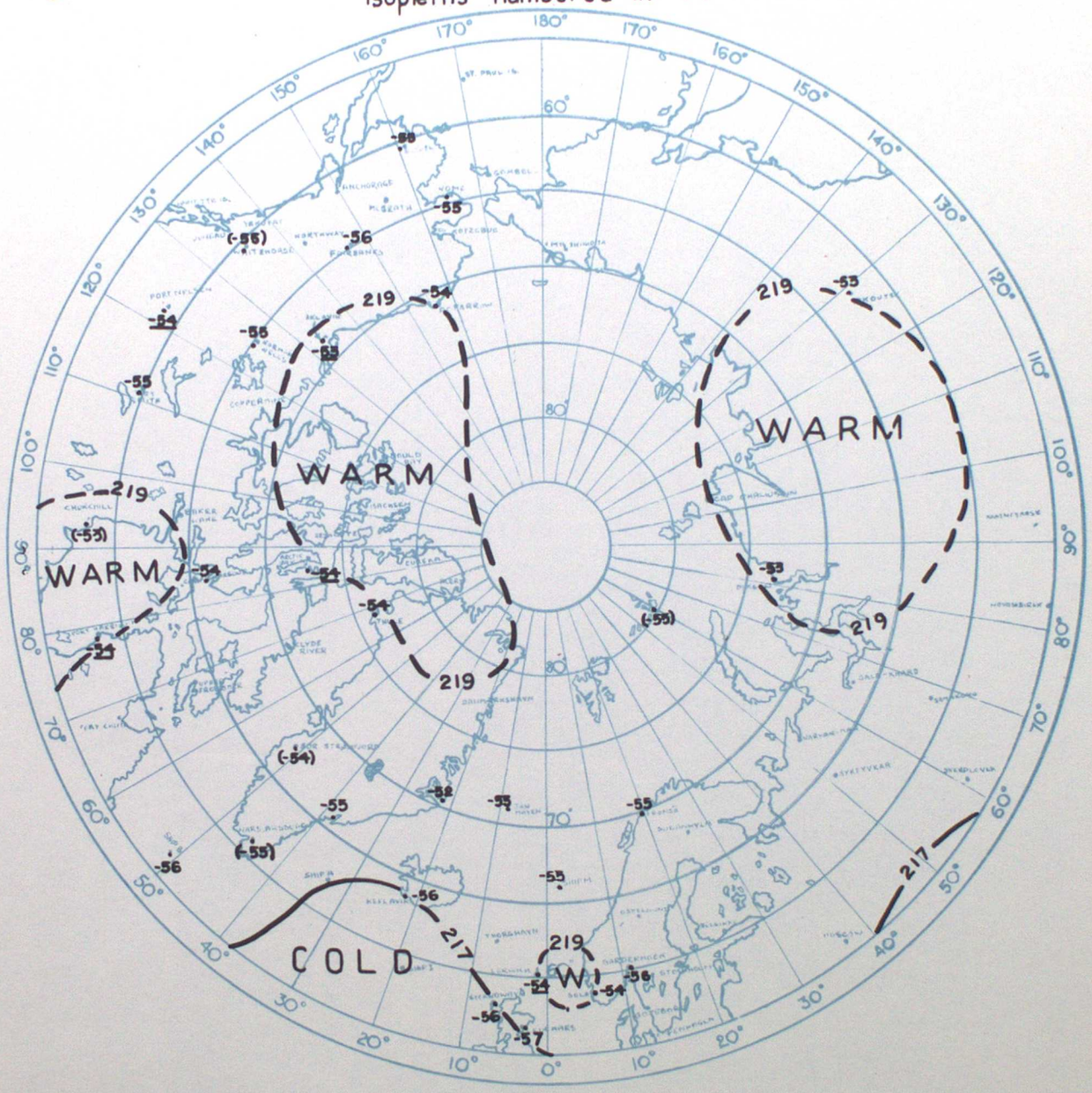
Polar tropopause

Areas in which frequencies of occurrence of both tropopauses are greater than 10%

M.R.P. 874

Fig. 6(b) TROPOPAUSE TEMPERATURE (°C) April

Isopleths numbered in °A



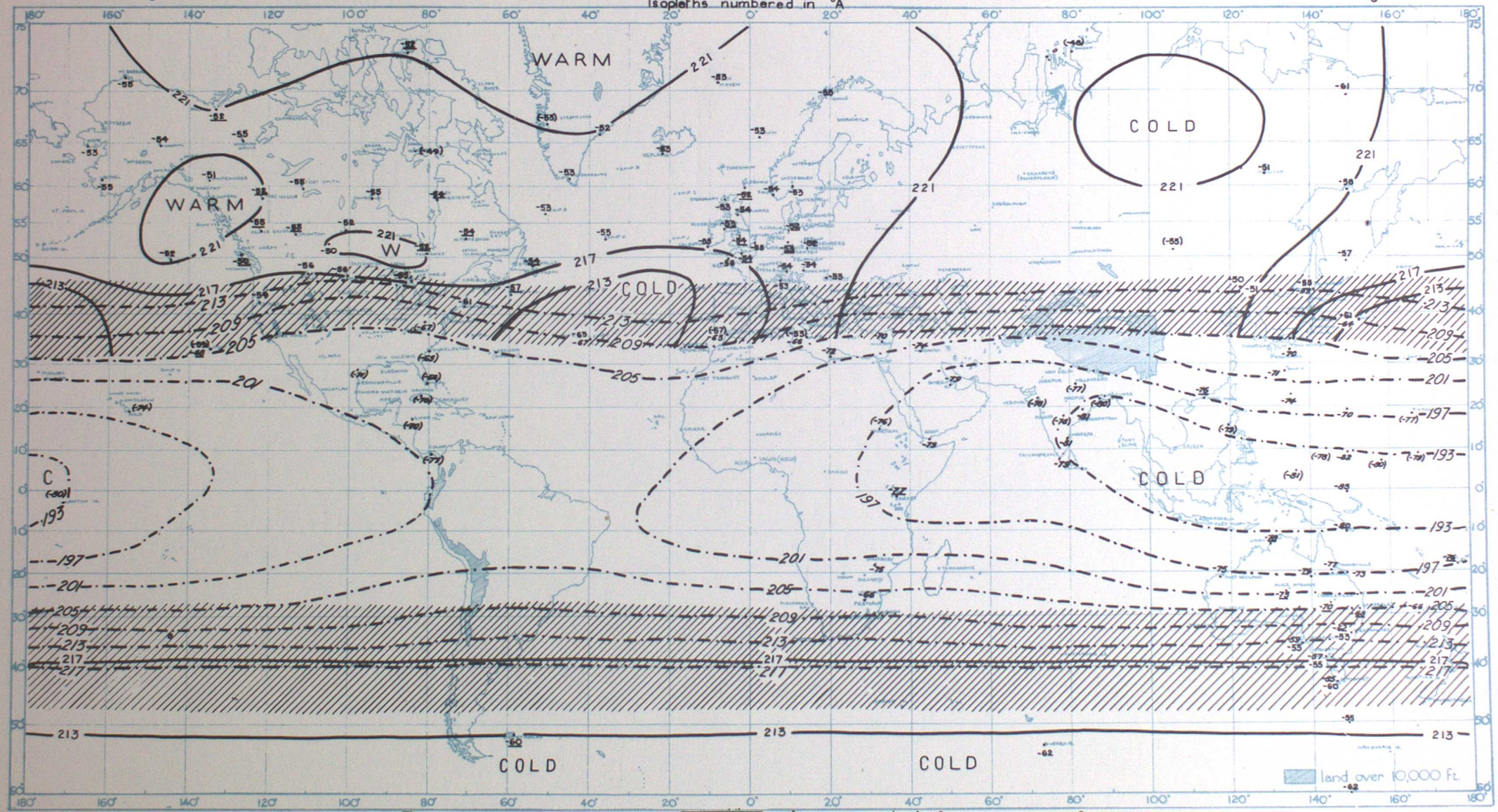
——— Polar tropopause

Fig. 7(a)

TROPOPAUSE TEMPERATURE (°C.)

Isopleths numbered in °A

July M.R.P. 874



M.R.P. 874

Fig. 7(b) TROPOPAUSE TEMPERATURE (°C) July

Isopleths numbered in °A

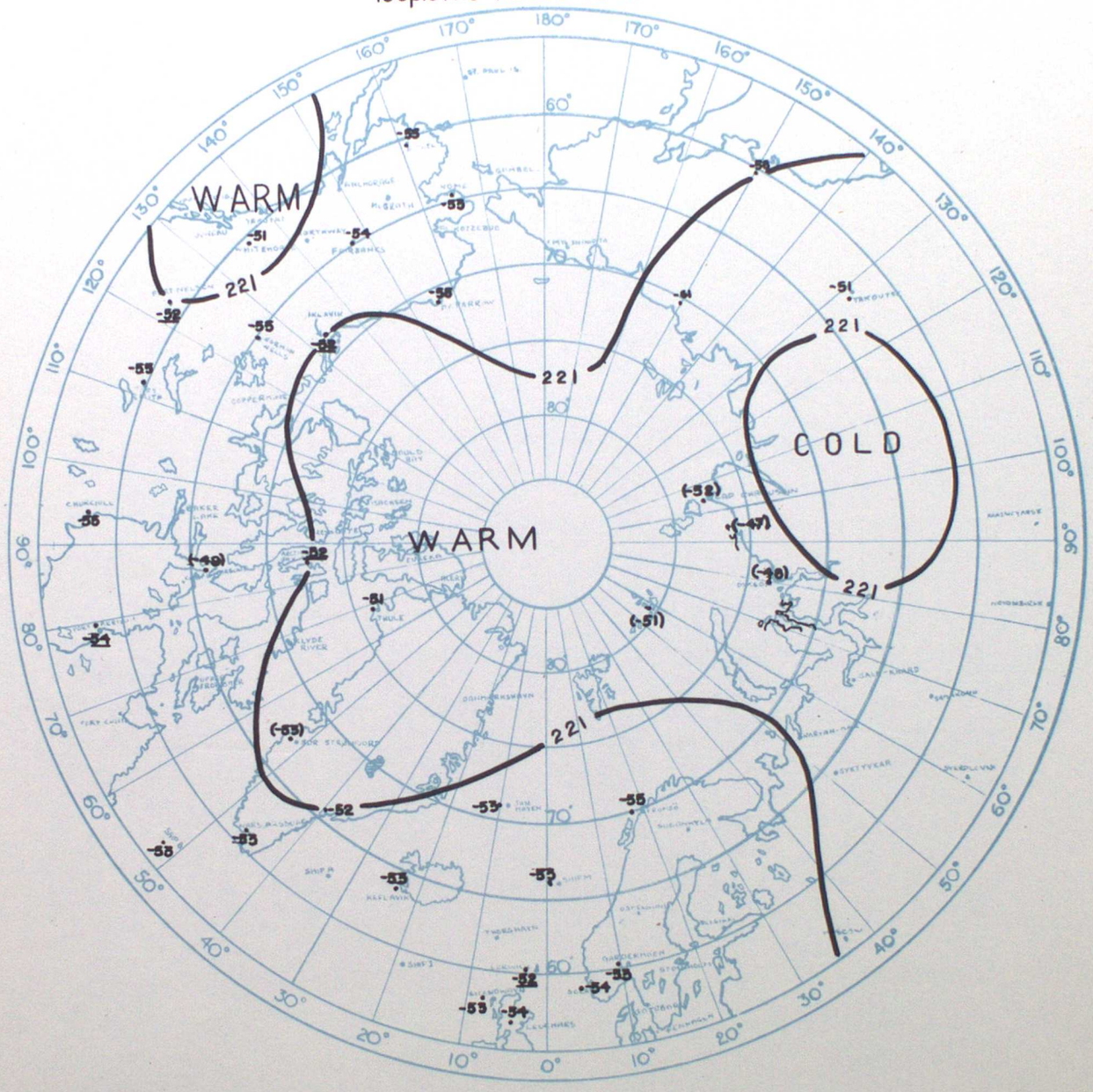
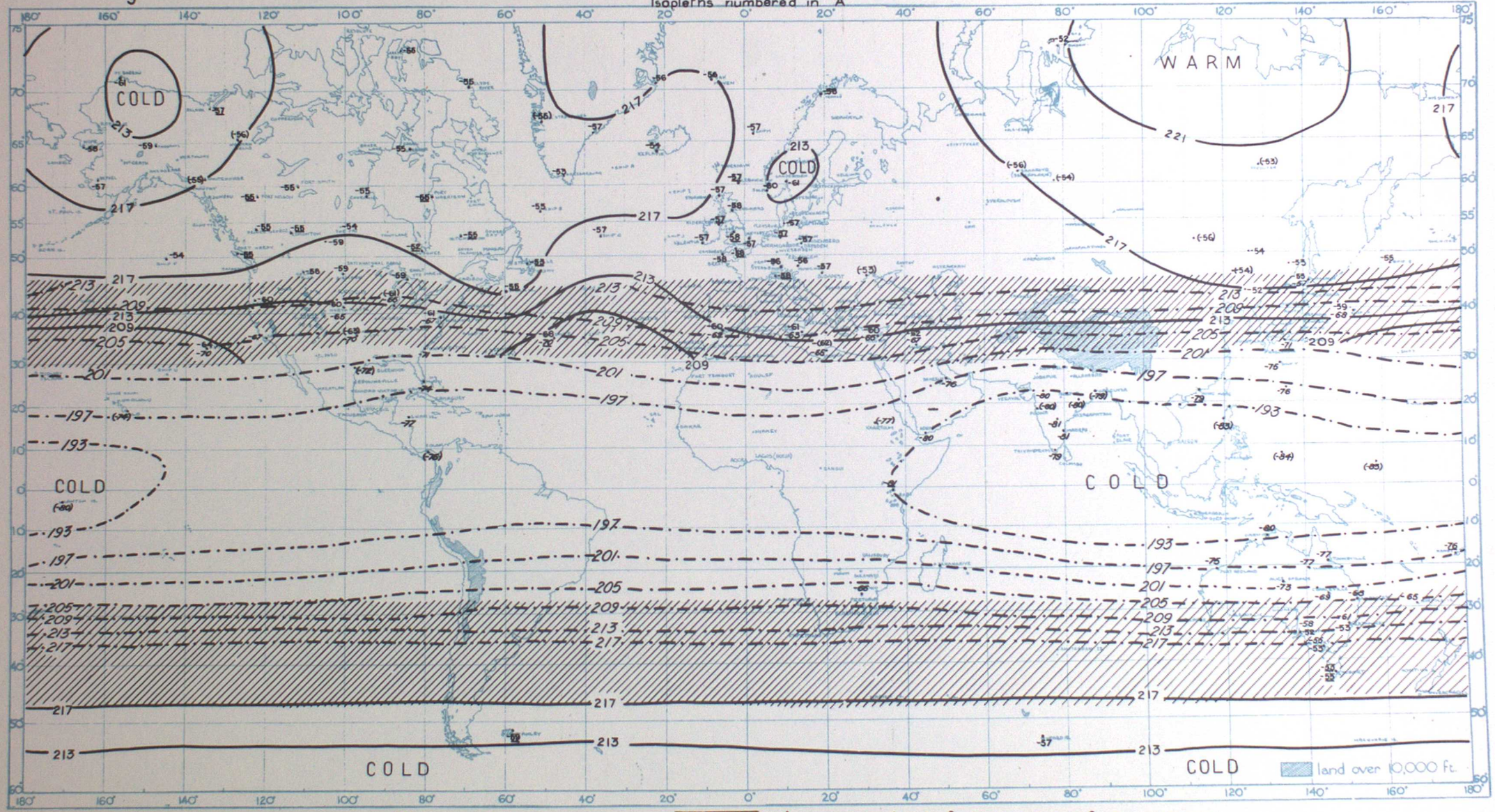


Fig. 8(a)

TROPOPAUSE TEMPERATURE (°C)

October M.R.P. 874

Isopleths numbered in °A



—·—·—·— Tropical tropopause

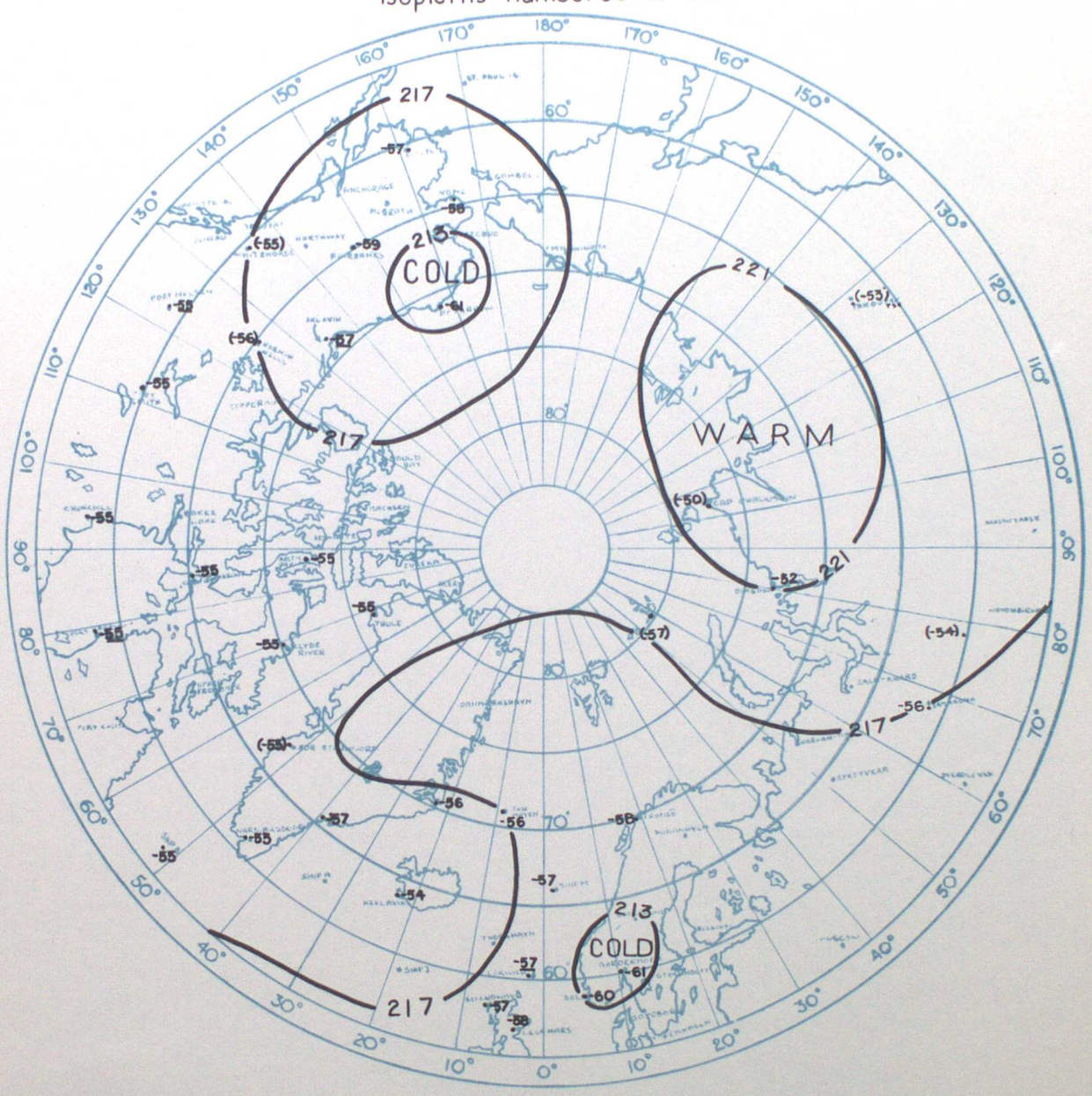
——— Polar tropopause

Areas in which frequencies of occurrence of both tropopauses are greater than 10%

M.R.P. 874

Fig. 8(b) TROPOPAUSE TEMPERATURE (°C) October

Isopleths numbered in °A



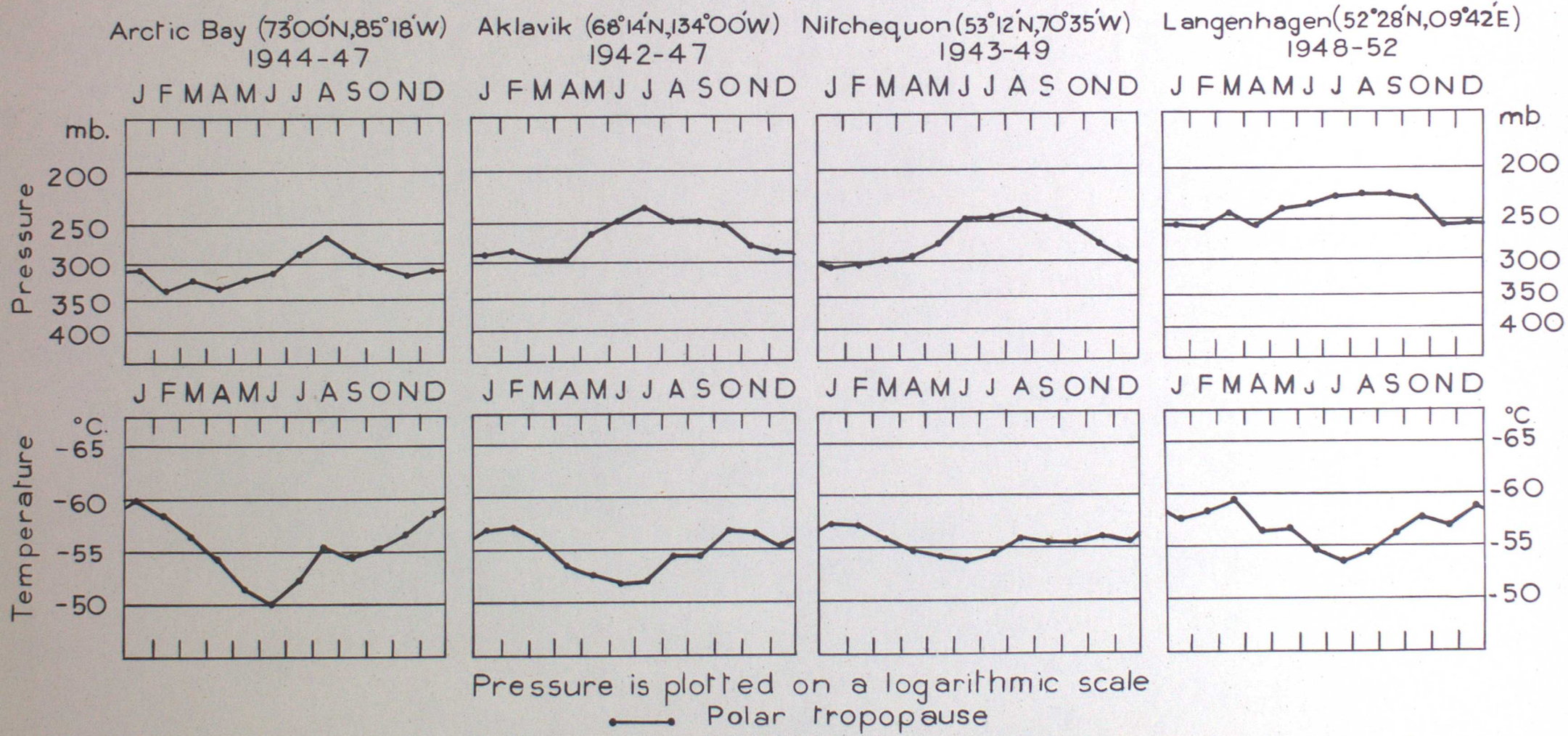


Fig.9. Annual variation of the mean monthly tropopause pressure and temperature

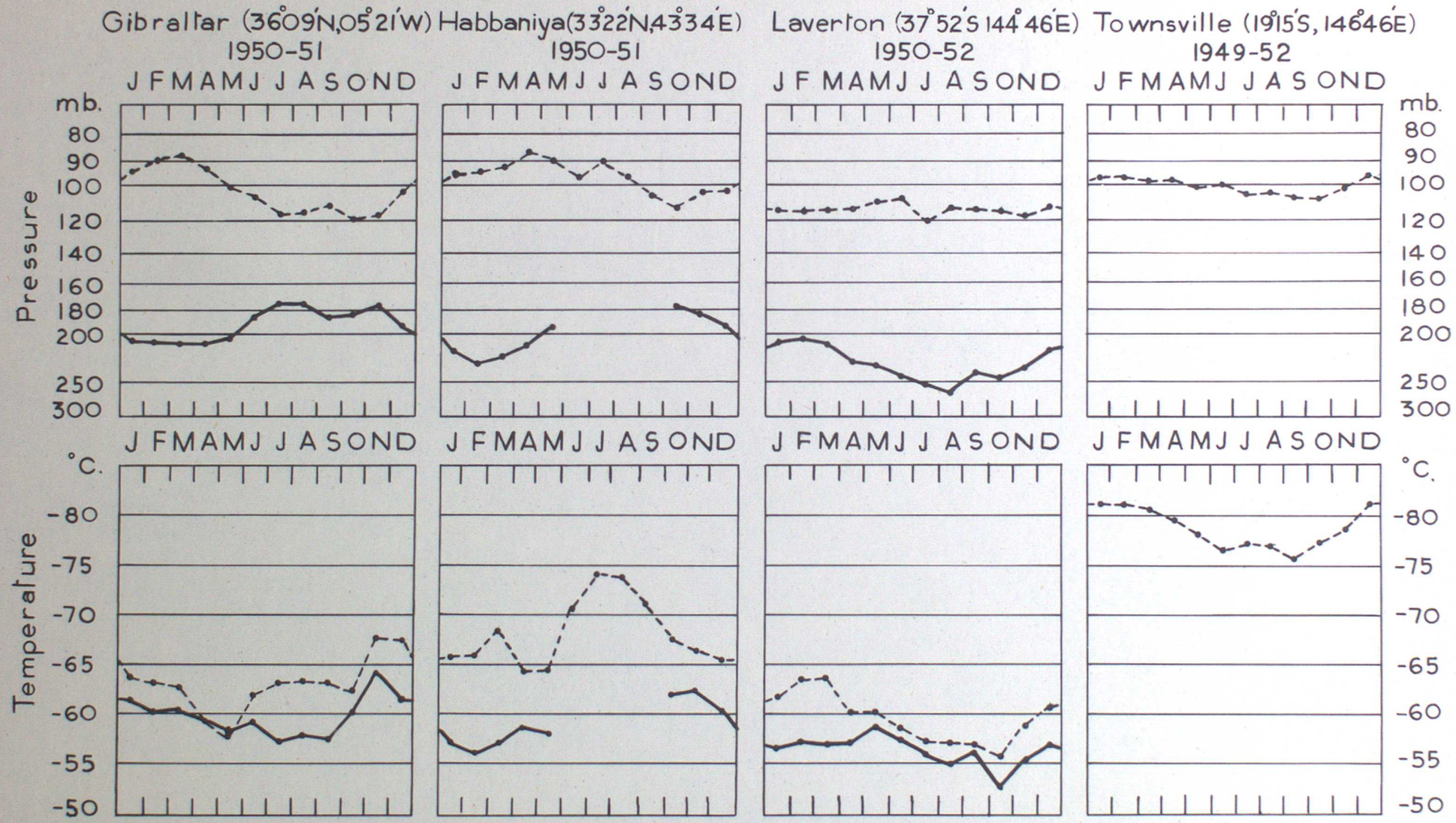


Fig.10. Annual variation of the mean monthly tropopause pressure and temperature